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(54) **Coriolis mass flow sensor with two curved measuring tubes**

(57) In a Coriolis mass flow sensor with two curved measuring tubes (1, 2), which are positioned opposite other in mirror symmetry to a plane of symmetry E and which are set to oscillating essentially perpendicular to the plane of symmetry, both measuring tubes are positioned so that their planes of intersection E1, E2 enclose an angle a smaller than 3°, in order to cancel forces lying in the plane of symmetry that occur in the ends of the tubes.

Description

[0001] The invention relates to a Coriolis mass flow sensor with two curved measuring tubes.
[0002] Coriolis mass flow meters are frequently employed to determine the mass flow of fluids in segments of pipelines.
Often functioning as the measurement sensors are two curved measuring tubes through which the fluid to be measured flows, and which are set to oscillating by means of an exciter arrangement. As a rule, the two measuring tubes are positioned opposite each other in mirror symmetry to a plane of symmetry, where the plane of symmetry lies between the two measuring tubes. In addition to measuring sensors with two curved measuring tubes, measuring sensors with two straight measuring tubes, or with only one straight or curved measuring tube, are also known.
[0003] The measuring tubes and the fluid together form a system capable of oscillating, which is normally excited at its resonant frequency. The resonant frequency depends on factors that include the material and the dimensions of the measuring tube; it also varies with the density of the flowing fluid.
In some cases, the measuring tube is not excited at the resonant frequency, but at a nearby frequency.
Two oscillation sensors detect the oscillating motion of the measuring tubes at two positions separated by some distance in the direction of flow, and convert the oscillating motion of the measuring tubes into sensor signals. Both sensor signals have the same frequency as the oscillating motion of the measuring tube, but they are phase-shifted with respect to each other.
The phase shifting is a measure of the mass flow.
[0004] The sensor signals are interpreted in a measurement sub-circuit and converted into a signal proportional to the mass flow of the fluid. Besides the mass flow, additional properties of the fluid, such as, for example, its density or viscosity can also be interpreted. To this end, for example, the frequency of the oscillating motion of the measuring tube is evaluated.
Known measurement sub-circuits operate either in analog mode, as described, for example, in EP -A698 783 and US- A 4,895,030, or digitally as described, for example, in EP- A 702 212 and US A5,429,002.
[0005] The quality of the measured result depends on factors such as how precisely the oscillating motion of the two measuring tubes can be registered. Interference that influences the sensor signals must be avoided insofar as possible here. Such interference occurs, for example, due to oscillation coupling of the measurement sensor with the process environment, in which oscillation energy is exchanged between the measurement sensor and the process environment. Oscillations can be transferred in that way from the process environment via the process connection of the sensor to the two measuring tubes, and are then picked up by the sensors and included in the evaluation.
Disturbance also comes from reflections, which may come about due to the fact that the measuring tube oscillations are conveyed from the sensor via the process connection into the process environment and can be reflected from there.
To prevent these disturbing influences, in the known sensors the two measuring tubes are positioned in mirror symmetry and parallel opposite each other, so that all oscillation components of the tube oscillations that are perpendicular to this mirror plane cancel each other out.
But because the two measuring tubes do not oscillate exactly parallel to each other, but perform a slight rotational movement, oscillation components also occur in the mirror plane that are not canceled, and thus lead to an unwanted oscillation coupling of the measurement sensor with the process environment.
[0006] The object of the present invention is to specify a sensor for a Coriolis mass flow meter that has better oscillation canceling and can be produced simply and inexpensively.
[0007] This object is solved by a Coriolis mass flow sensor having two curved measuring tubes that are positioned opposite each other in mirror symmetry to a plane of symmetry, and which are set to oscillating essentially perpendicular to the plane of symmetry, wherein the two measuring tubes are positioned so that their planes of intersection enclose an angle smaller than 3°, in order to cancel forces lying in the plane of symmetry that occur at the ends of the tubes.
[0008] The essential idea of the invention is that because of the oblique positioning of the two measuring tubes, forces that lie in the plane of symmetry are canceled. As a result, the oscillation coupling with the process environment is significantly reduced and the precision of measurement increased.
[0009] In an alternative design of the present invention, a Coriolis mass flow sensor has two curved measuring tubes that are positioned parallel to and opposite each other in mirror symmetry to a plane of

symmetry E, and which are set to oscillating essentially perpendicular to the plane of symmetry, there being extensions positioned at the middles of the tubes in order to cancel forces lying in the plane of symmetry that occur at the ends of the tubes.

[0010] In a preferred embodiment of the present invention, the two measuring tubes are connected to each other at their ends by means of two coupling elements.

[0011] In an additional preferred embodiment of the present invention, the angle a between the two intersecting planes is about 0.4°.

[0012] The present invention is explained in greater detail below on the basis of two exemplary embodiments represented in the drawing.

The figures show the following:

[0013]

Figure 1 shows a schematic top view of a first mass flow sensor according to the present invention;

Figure 2a is a sketch of the principle explaining the oscillating motion in a sensor according to the prior art;

Figure 2b is a sketch of the principle explaining the oscillating motion in a Coriolis mass flow sensor according to Figure 1;

Figure 3 shows a schematic top view of a second Coriolis mass flow sensor according to the present invention.

[0014] Figure 1 shows a schematic top view of a first Coriolis mass flow sensor according to the present invention, which is designated below as sensor 10.

[0015] Sensor 10 has a measuring tube 1 bent essentially in a V shape in a first plane of intersection L1, which is curved symmetrically with respect to a first line of symmetry.
A V-shaped curved second measuring tube 2 with a plane of intersection L2 is positioned in mirror symmetry to measuring tube 1 with respect to a plane of symmetry E.
The plane of symmetry E is centered between the two measuring tubes 1, 2.

[0016] Both measuring tubes 1 and 2 are of one-piece construction.

[0017] Measuring tube 1 has a straight inlet piece 11, which is aligned with a straight outlet piece 12.

[0018] Measuring tube 2 also has a straight inlet piece 21, which is aligned with a corresponding straight outlet piece 22.

[0019] Connected to the straight inlet piece 11 of measuring tube 11 is a curved inlet piece 13, which gives way to a straight tube segment 15. The straight tube segment 15 gives way to a vertex curve 17, to which another straight tube segment 16 is connected, from which an outlet curve 14 leads to the straight outlet segment 12.

[0020] Measuring tube 2 is constructed corresponding to measuring tube 1.
Connected to the straight inlet piece 21 of measuring tube 2 is an inlet curve 23, which gives way to a straight tube segment 25. The straight tube segment 25 gives way to a vertex curve 27, to which another straight tube segment 26 is connected, from which an outlet curve 24 leads to the straight outlet segment 22.

[0021] Both measuring tubes 1, 2 are connected to each other through two coupling elements 51, 52 on the inlet side, and through two coupling elements 53, 54 on the outlet side.

[0022] The inlet pieces 11, 21 are fixed in an inlet distributor piece 18, and the outlet pieces 12, 22 are fixed in an outlet distributor piece 19. The two distributor pieces 18, 19 are mounted in a support frame 30, which is part of a housing that is not shown in greater detail.

[0023] The measuring tubes 1, 2 and the distributor pieces 18, 19 are made of stainless steel in the exemplary embodiment.

[0024] In operation, the sensor 10 is integrated into a pipeline segment, not shown in greater detail, through a process connection.
These pipelines differ in ways specific to the customer, so that measuring sensor 10 may have different connecting devices (threaded nipples, flanges or clamping devices) as process connections.

[0025] Like the measuring tubes 1, 2, the support frame 30 is made in one piece.

[0026] Support frame 30 is welded on the front and back to sheet metal pieces, not shown in greater detail, so that the two measuring tubes are in a housing with an air-tight seal.

[0027] With the help of a known exciter arrangement 6, not shown in greater detail, which is fixed to the vertex curves 17, 27, the two measuring tubes 1, 2 are set to oscillating in a tuning fork-like manner, at an oscillation frequency that corresponds to the resonant frequency of the system of measuring tube 1, 2 including the fluid present in the two measuring tubes. In some cases the oscillation frequency is also somewhat off the resonant frequency.

[0028] The resonant frequency of the system depends on the density of the fluid. The density of the fluid can therefore be determined from the resonant frequency.

[0029] The exciter arrangement 6 is supplied with alternating energy by a driver circuit, not shown, through a supply circuit 63; it may be, for example, a PLL circuit that always sets the present resonant frequency of the system, corresponding to US 4,801,897.

[0030] The oscillating motion of the two measuring tubes 1, 2 is detected by two distance or velocity sensors 7, 8, which are fixed to the straight tube segments 15, 25 or 16, 26, and are connected via connecting lines 73, 83 to a measuring sub-circuit, not shown.

[0031] Evaluation of the signal is not the object of the present invention, so that more precise representation of a measuring sub-circuit will be dispensed with. Such sub-circuits are described, for example, in publications EP- A698 738, US- A 4,895,030 EP- A702,212 and US A 5,429,002.

[0032] Figure 2 a shows a sketch of the principle explaining the oscillating motion in a sensor according to the prior art, with two parallel measuring tubes. Corresponding parts in Figure 2 are coded in accordance with Figure 1.

[0033] Shown in side view in simplified form are two measuring tubes 1, 2 positioned parallel, but whose ends are not fixed but can oscillate freely, and which are connected with each other through two coupling elements 51, 52. All non-essential parts are not shown, for the sake of clarity.

[0034] The idea of the present invention can be explained better on the basis of freely oscillating ends.
In operation, the two measuring tubes 1, 2 oscillate relative to each other. The displacement of the vertex curves 17, 27, shown by arrows P1, P2 is produced by an exciter arrangement 6, not shown. The major part of the oscillation amplitude is in the x direction. But there is also a smaller part of the oscillation amplitude in the y direction.
The force of the exciter arrangement 6 is transmitted through the measuring tubes 1, 2 to the coupling elements 51, 52. The coupling elements 51, 52 become deformed as shown. The middles of the coupling elements 51, 52 move in the y direction, while the outer ends move in opposition in the -y direction.
At the same time, the ends of the measuring tubes 1, 2 move in the y direction. This can be seen more clearly from the corresponding top view of a measuring tube 1 or 2.
When the measuring tube ends are in the fixed state, this motion in the y direction leads to a force on the distributor pieces 18 or 19.

[0035] Figure 2b shows a corresponding sketch of the principle for a sensor according to Figure 1. This sensor differs from the sensor according to Figure 2a only in the oblique position of the measuring tubes.
Because of the oblique position of the two measuring tubes 1, 2, the vertex curves 17, 27 move somewhat in the y direction during the oscillating motion. This y motion cancels the corresponding -y motion of the tube ends, so that the tube ends remain in principle in a fixed position.
Therefore, in the fixed state of the tube ends, there is no force acting on the distributor pieces (18, 19).
This causes the coupling of the measuring sensor 10 with the process environment to be reduced substantially.

[0036] In Figure 2a and Figure 2b, the deflection is exaggerated in the interest of clarification.

[0037] Figure 3 shows a schematic top view of a second Coriolis mass flow sensor according to the present invention. This sensor 10' differs from the sensor according to Figure 1 only in the fact that the two measuring tubes 1, 2 are positioned parallel to each other, and that there are extensions 90a, 90b located respectively on the vertex curves 17, 27, which produce a component of motion in the plane of symmetry during the oscillating motion of the measuring tubes, which acts counter to the motion of the free ends of the tubes. That reduces the oscillating motion of the tube ends.
In the fixed state of the tube ends there is no force acting on the distributor pieces 18, 19.
As a result, the coupling of the measurement sensor 10' with the process environment is reduced substantially in this case also.

[0038] The advantages of the present invention have also been verified by FEM calculations and corresponding experiments.

Claims

1. A Coriolis mass flow sensor with two curved measuring tubes (1, 2), which are positioned opposite each other in mirror symmetry to a plane of symmetry E and are set to oscillating essentially perpendicular to the plane of symmetry, wherein the two measuring tubes are positioned so that their planes of intersection E1, E2 enclose an angle a smaller than 3°, in order to cancel forces lying in the plane of symmetry that occur at the ends of the tubes.

2. The Coriolis mass flow sensor according to Claim 1, wherein the angle a is 0.4°.

3. A Coriolis mass flow sensor with two curved measuring tubes (1, 2), which are positioned opposite each other in mirror symmetry to a plane of symmetry E and are set to oscillating essentially perpendicular to the plane of symmetry, wherein there are extensions (90a, 90b) positioned at the middles of the tubes, in order to cancel forces lying in the plane of symmetry E that occur at the ends of the tubes.

4. The Coriolis mass flow sensor according to one of the preceding claims, wherein the ends of the tubes are connected with each other through coupling elements (51, 52, 53, 54).

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EUROPEAN RESEARCH REPORT

Number of the application
EP 01 10 8574

RELEVANT DOCUMENTS			
Category	Identification of the document, designating the significant parts, where necessary	Pertaining to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 7)
X	US 5,394,758 A (WENGER, ALFRED, ET AL) 7 March 1995 (1995-03-07) * Column 3, Line 54 – Column 5, Line 17; Figures 1, 2 * ---	1-4	G01F1/84
A	US 5,602,344 A (LEW, HYOK S, ET AL) 11 February 1997 (1997-02-11) * Column 13, Line 9 – Line 55; Figure 7 * ---	1-4	
A	US 5,700,957 A (BUSZNYAK, IMRE, ET AL) 23 December 1997 (1997-12-23) * Column 6, Line 24 – Column 8, Line 45; Figure 7 * ---	3, 4	
A	EP 0 831 306 A (OVAL CORP) 25 March 1998 (1998-03-25) * Column 13, Line 48 – Line 58; Claim 6; Figure 6 * -----	3	RESEARCHED FIELDS (Int. Cl. 7) G01F

The present research report was prepared for all patent claims

Research location	Closing date of the search	Examiner
MUNICH	12 September 2001	Penzl, B

CATEGORY OF THE NAMED DOCUMENTS

X: of special importance by itself
Y: of special importance in combination with another publication of the same category
A: technological background
O: unwritten disclosure
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T: theories or principles on which the invention is based
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ADDENDUM TO THE EUROPEAN RESEARCH REPORT FOR EUROPEAN PATENT APPLICATION NO. EP 01 10 8574

This supplement specifies the members of the patent families of the patent documents listed in the above mentioned European research report.
The information about the family members corresponds to the state of the file of the European Patent Office on
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12 September 2001

Patent document cited in the research report	Date of publication	Member(s) of the patent family	Date of publication

For further details relating to this supplement: see Official Gazette of the European Patent Office, No. 12/82

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